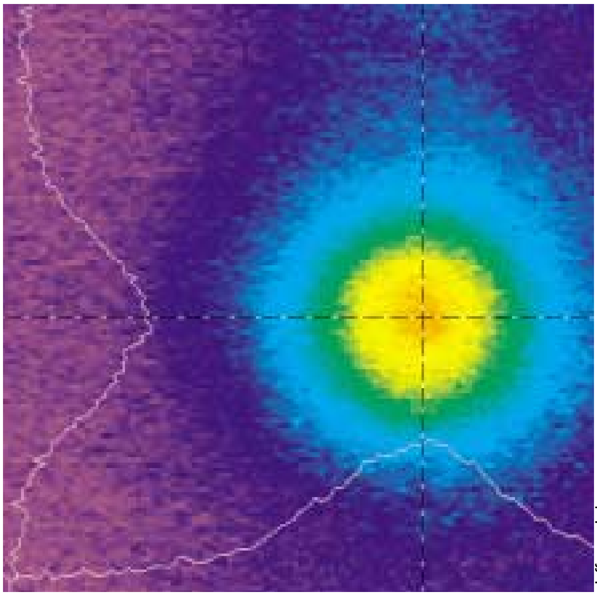
Twenty watts of terahertz

Terahertz radiation, also known as submicrometer radiation, is the latest frontier in the electromagnetic spectrum. Coherent sources produce electromagnetic waves extending from wavelengths of 100,000 km to 0.1 μm, but until recently the region between around 100 and 300 μm had no good coherent sources. Such terahertz waves have a range of potential applications, especially in biomedicine, where they can be used to analyze surface proteins of living tissues to provide instant "biopsies" for diseases such as skin cancers.



Jefferson Lab

Terahertz radiation coming through a window from the free-electron laser is reflected by a mirror onto the detector array of a pyroelectric camera to produce this false-color, real-time video image.

Current methods of producing teraherz radiation, however, yield a limited average power of only about 1 mW. A pulse of light from a femtosecond laser, for example, can accelerate electrons to high-peak-power pulses, but the total amount of radiation from each pulse is low, and so is average power output. Now, a collaborative effort among three national laboratories—Brookhaven (Upton, NY), Lawrence Berkeley (Berkeley, CA), and the Thomas Jefferson National Accelerator Facility (Newport News VA), commonly called the Jefferson Lab—has achieved an average output of 20 W using relativistic electrons from a linear accelerator, or linac (*Nature* **2002**, *420*, 153).

The new method begins with the production of a picosecond-long pulse of electrons generated by exposing gallium arsenide to a femtosecond laser. The electrons are then fed into the 30-m-long linac at the Jefferson Lab's free-electron laser (FEL) to boost their energy to 40 MeV. The accelerated electrons are bent by a magnetic field into a 1-m arc. As they are accelerated through this curve, they radiate in the terahertz range.

Although the number of electrons in each pulse is comparable to that produced by existing techniques, the amount of energy each electron radiates increases as the fourth power of the relativistic factor, or of the energy. For 40-MeV electrons, this means a 200,000-fold increase in power over subrelativistic electrons. With a repetition rate of 37 MHz, the Jefferson Lab's FEL linac produces a 5-mA current and a 20-W radiation output.

The efficiency of the entire system is greatly enhanced because after the electrons radiate, they are fed back into the accelerator to decelerate them back down to 10 MeV. Thus, about three-quarters of the energy of the electrons is fed back into the power supply, reducing total power input by a factor of 4.

"Of course, a 30-m-long accelerator is not a practical source for medical diagnostics," says Gwyn P. Williams of the Jefferson Lab, one of the researchers. "But we are currently looking at what the minimum parameters needed for adequate power are. We expect that we will be able to reduce accelerator length to 2 to 3 m and perhaps the cost to that of an MRI scanner." The team is now working with Advanced Energy Systems (Medford, NY) to develop a compact system for commercialization.

Such a terahertz scanner could detect skin cancer on a patient without a biopsy and substitute spectral analyses for biopsies in endoscopic procedures such as colonoscopies. (Terahertz radiation does not penetrate tissue well, so it cannot probe for diseases located much below the surface.) Because terahertz radiation does penetrate cloth and paper easily, other possible applications include security scanners.

Chaos in the engine

One of the fastest ways to reduce fossil-fuel use is to increase the energy efficiency of machines, and one of the less-efficient machines is the internal combustion engine—despite a century of development. One cause of this inefficiency is the stroke-to-stroke variation in the power supplied by each piston. Because the crankshaft can absorb only a set amount of power at a given rotation rate, variations in the energy generated by each piston cause wasted power, which goes into engine noise. Eliminating such variability would increase engine efficiency by about 10% and save enormous amounts of fuel each year.

Researchers at the Technical Institute of Lublin (Poland) have found clues to how this stroke variability develops, clues that may aid in reducing it (http://arXiv.org/abs/nlin/?0212050). Using a fiber-optic-based pressure measurement system, they obtained continuous recordings of pressure in a single piston with high time resolution. They showed that in certain types of operation, the variation of pressure in the cylinder became chaotic. Chaotic variability, although not random, is characterized by a strongly nonperiodic variability that is difficult to control by any conventional feedback mechanism.

The key parameter in the onset of chaos, the Lublin team discovered, was the ignition advance angle, defined as the difference in the angular position of the crankshaft between the time that the spark ignites combustion and the time of maximum compression. The larger the advance angle, the higher the torque and the larger the efficiency of the energy conversion, other factors being equal. But the team